# High pt opportunities at RHIC-II using a new detector concept (R2D)

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**RHIC-II workshop,**
**Brookhaven National Laboratory**
**April 29th/30th, 2005**

# Talk structure

- What is R2D ?
- Relevant RHIC-I results
- Future non-identified particle measurements
- Future identified particle measurements in pp
- Future identified particle measurements in AA
- Summary

# Expression of Interest -
# A Comprehensive New Detector for RHIC II

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M. Calderon (Indiana University)
J. Rak (University of New Mexico)
S. Margetis, C.Markert (Kent State University)
M.A. Lisa, D. Magestro, B. Petrak (Ohio State University)
R. Lacey (State University of New York, Stony Brook)
G. Paic (UNAM Mexico)
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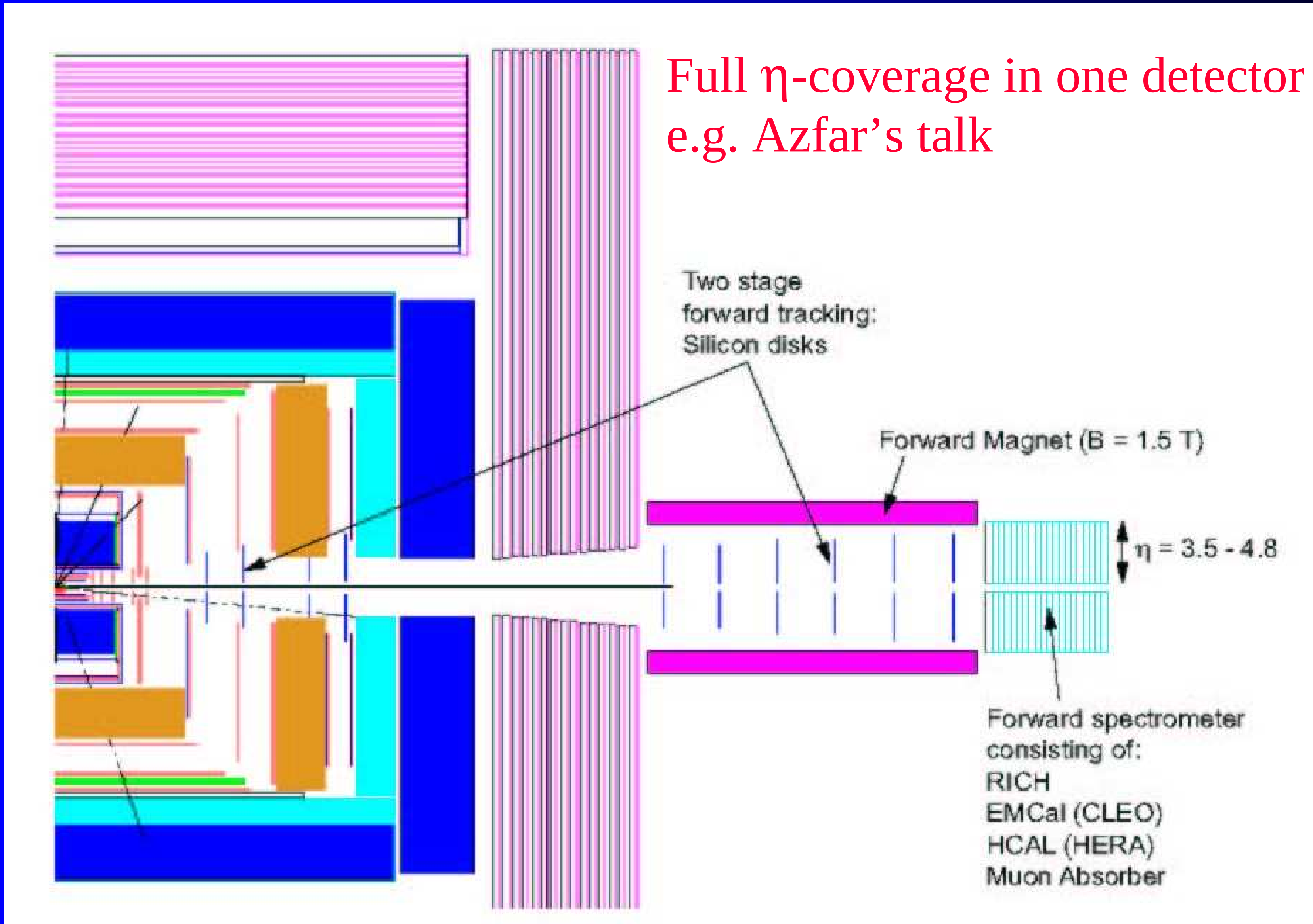
and
H. Caines, A. Chikanian, E. Finch, J.W. Harris, M.A.C. Lamont,
J. Sandweiss, N. Smirnov (Yale University)

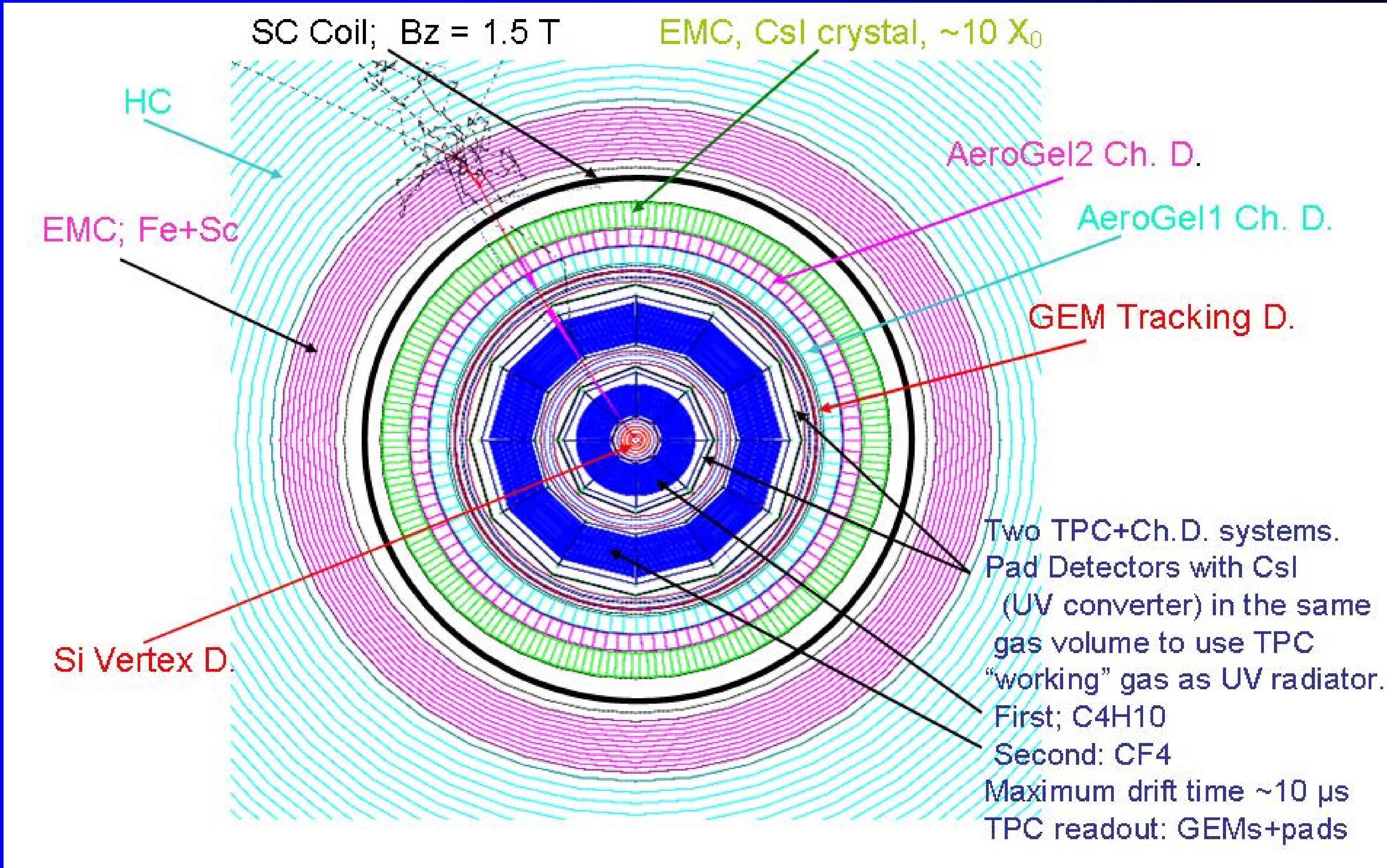
(~80 pages, submitted in August 2004,nucl-ex/0503002)

# R2D detector concept: hermeticity and PID

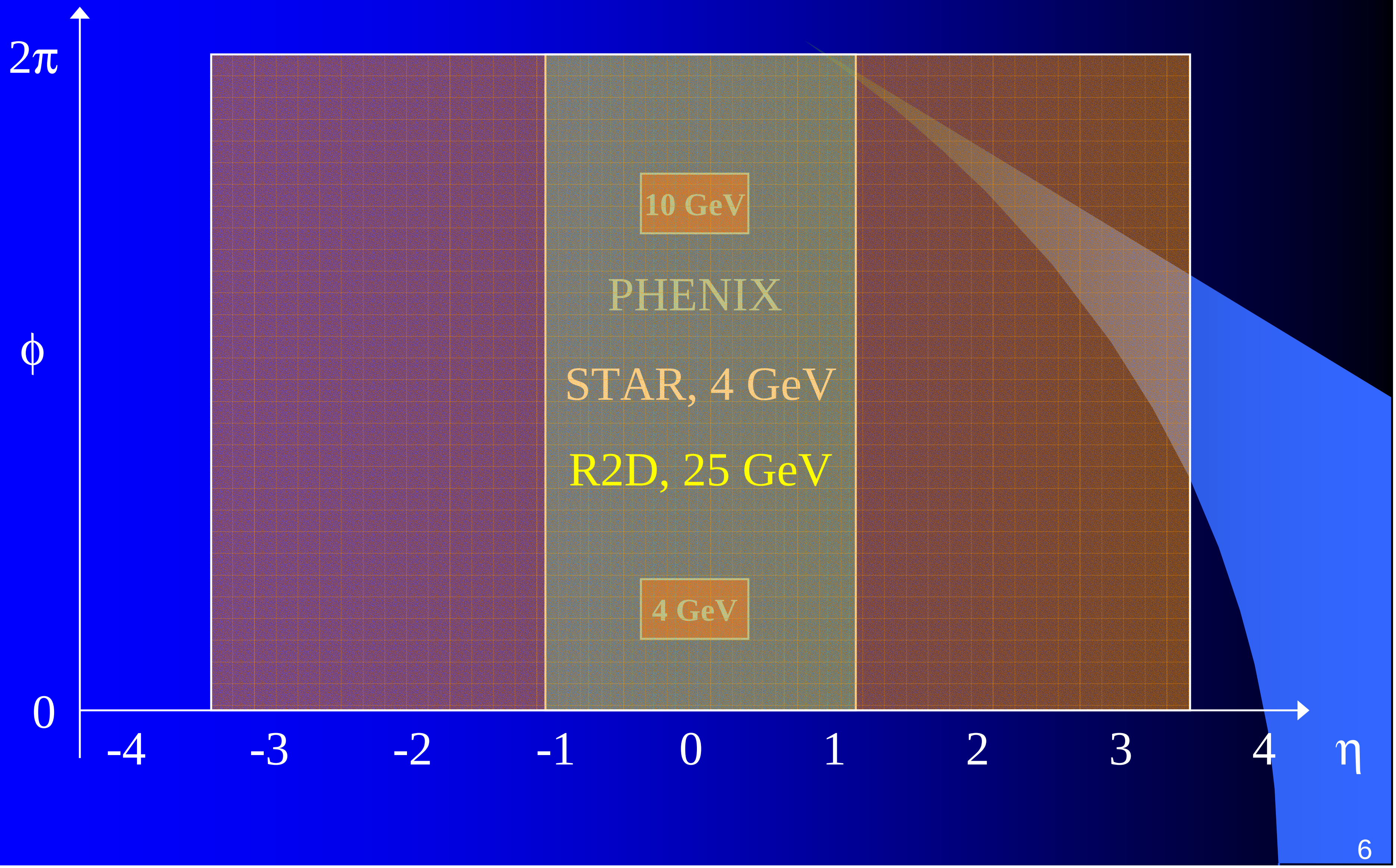


# Alternative: S-R2D based on CDF

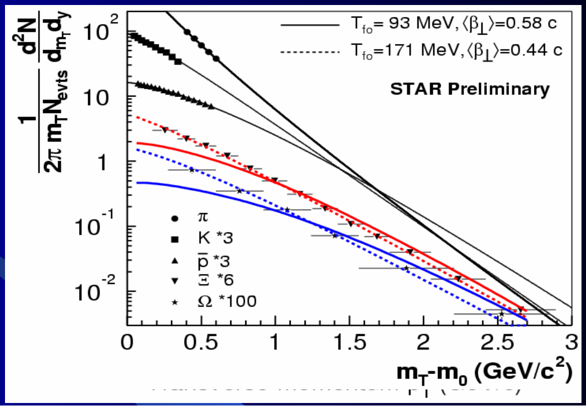
(CDF, CLEO & BABAR have same field and magnet radius)



# We need high pt PID and large acceptance !

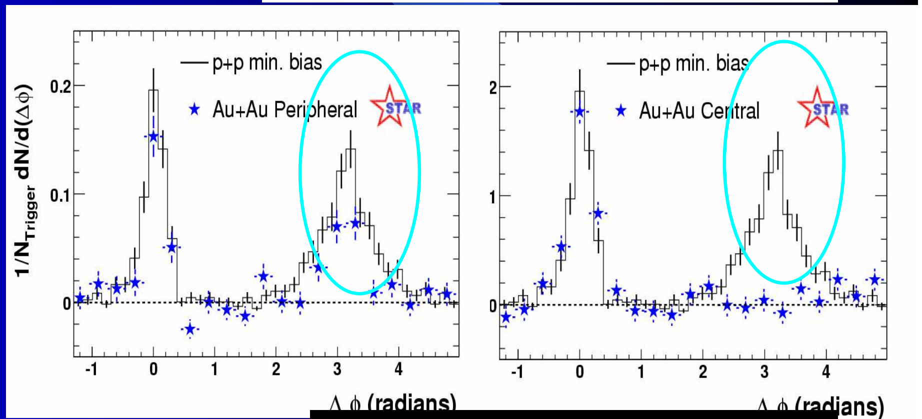


# Relevant RHIC-I results



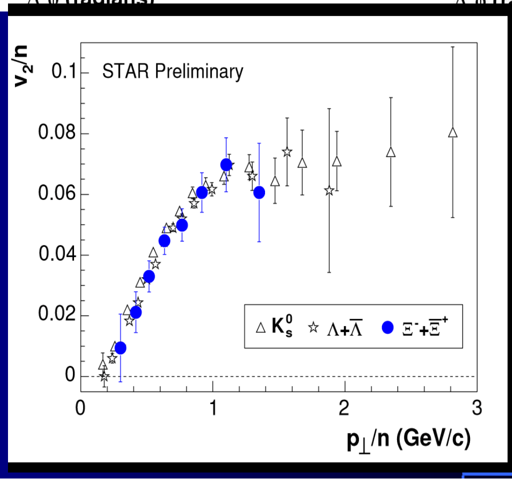

## Hydrodynamics:

Strong collectivity in a liquid like (not plasma) phase which requires a partonic EoS




## Jet Quenching:

The ‘quenching’ of high pt particles due to radiative partonic energy loss.
Energy loss 15 times higher (several GeV/fm3 ) than in cold nuclear matter (compare RHIC AA to HERMES eA)

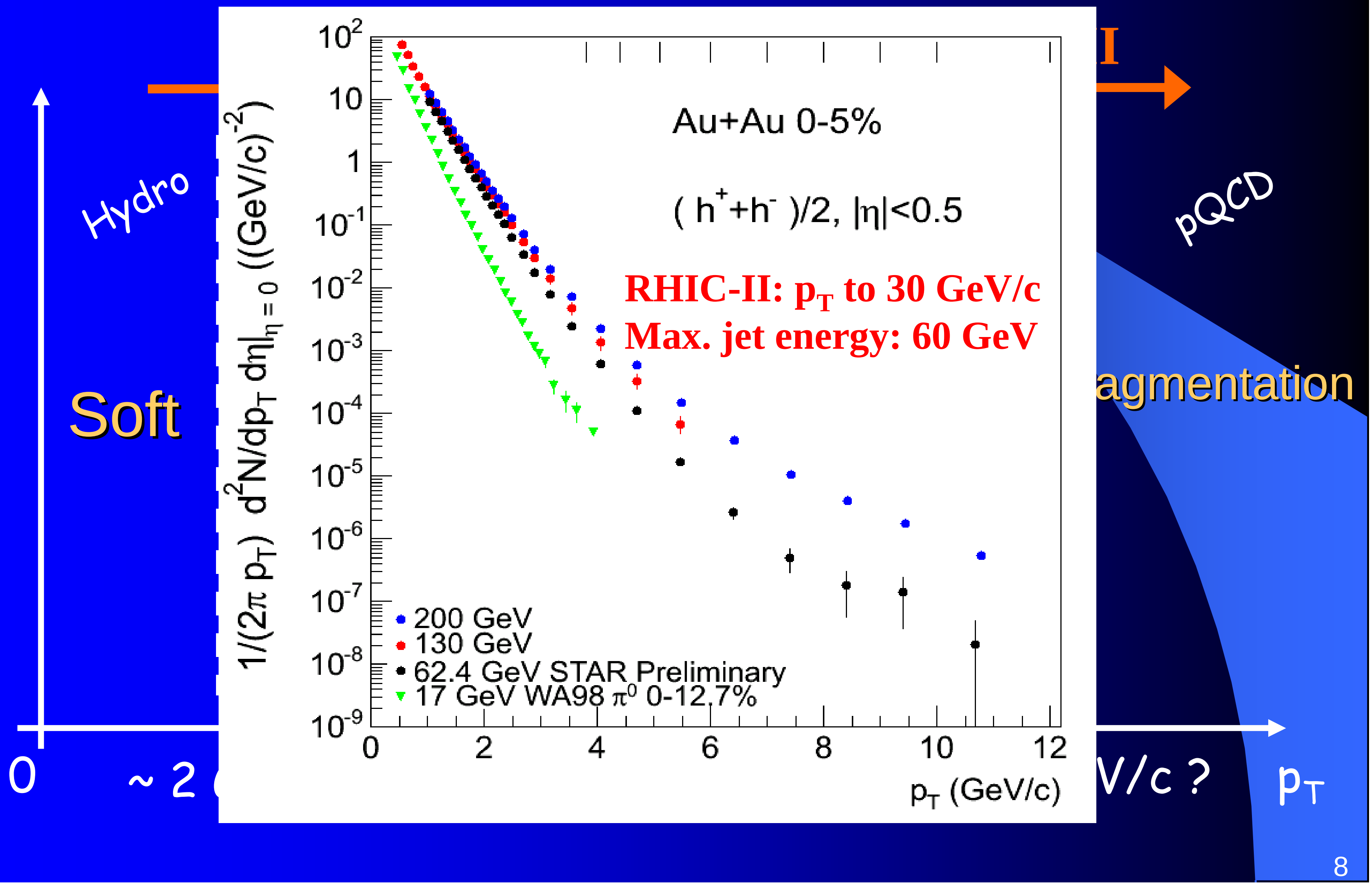



## Constituent quark scaling:

recombination provides a description ~1.5 - 5 GeV/c for identified particle properties
Caveat: string fragmentation might too !!

v2 and jet quenching probe d.o.f above Tc !

# Contributions to particle production in RHI collisions



# High pt physics based on non-identified spectra

# Medium Induced Non-Abelian Radiative Spectrum

- In an expanding medium the gluon rapidity density is the relevant jet quenching parameter

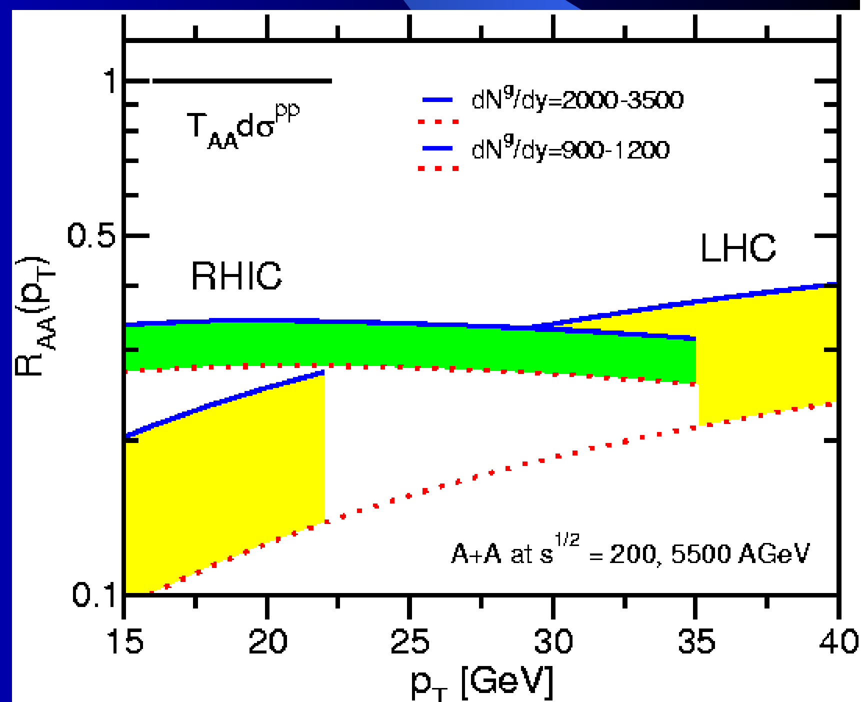
$$\Delta E^{(1)} \approx \frac{C_R \alpha_s}{4} \frac{\mu^2 L^2}{\lambda_g} \mathrm{Log} \frac{2E}{\mu^2(L) L} + \dots ,$$

– Static medium

$$\Delta E^{(1)} \approx \frac{9\pi C_R \alpha_s^3}{4} L \frac{1}{A_\perp} \frac{dN^g}{dy} \mathrm{Log} \frac{2E}{\mu^2(L) L} + \dots ,$$

– 1+1D Bjorken

- The density at the LHC is 2-3 times larger. This pT range is dominated by gluons, not quarks, at the LHC




Underlying spectrum

$$d\sigma \propto 1/p_T^{\,n}$$

Suppression factor

$$R_{AA}(p_T) = (1 + c \cdot \Delta p_T / p_T)^{-(n-2)}$$

$$\frac{\Delta p_T}{p_T} \approx \frac{\Delta E}{E} \propto \frac{L}{A_\perp}\frac{dN}{dy} \propto N_{part}^{\,2/3}$$

**Note that near threshold n increases leading to larger suppression**

slide from I.Vitev

# Quantifying the modification of fragmentation functions through γ-tagged jets (e.g.hep-ph/0310274)

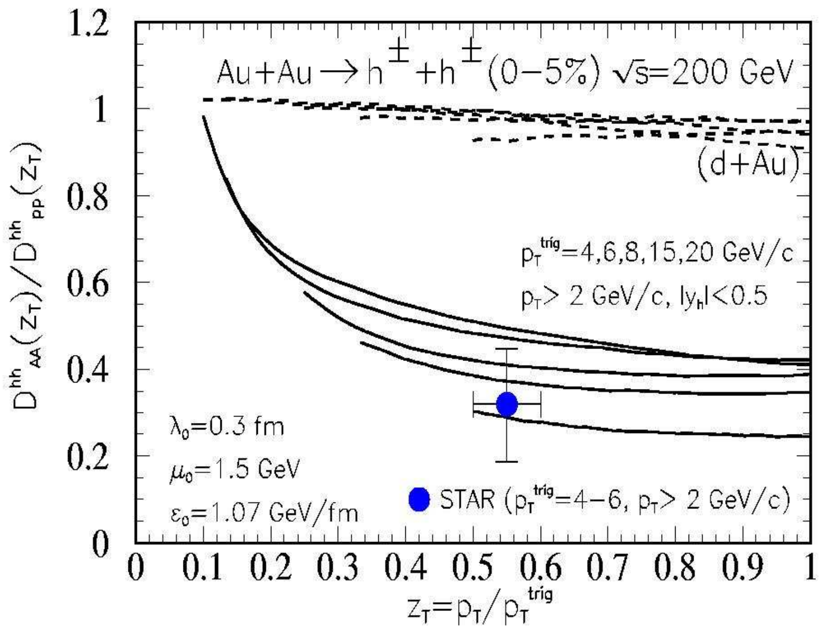



Fig. 46: The suppression factor for hadron-triggered fragmentation functions in central (0-5%) $Au + Au$ (d+Au) collisions as compared to the STAR data [24].

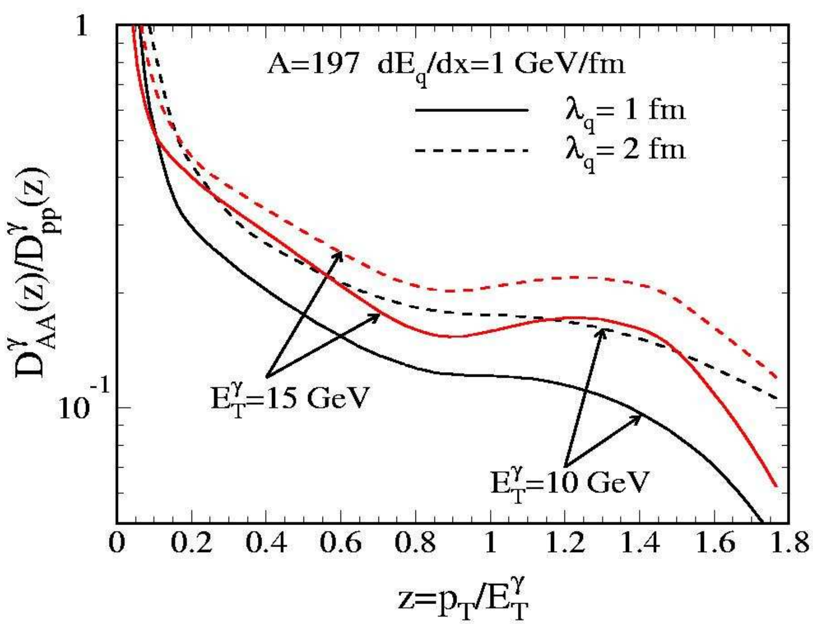


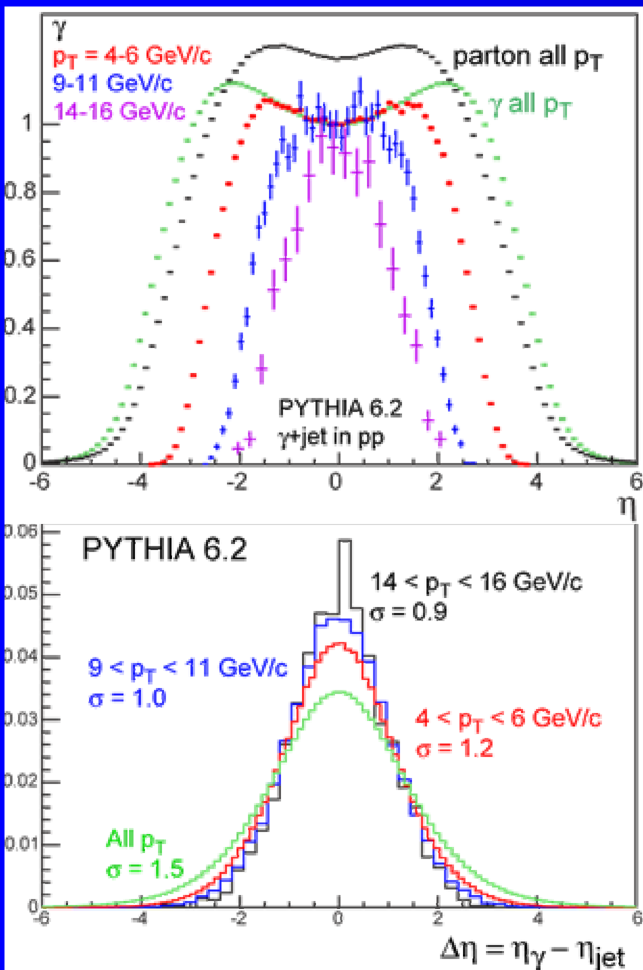

Fig. 47: The modification factor of the photon-tagged inclusive jet fragmentation function in central $Au+Au$ collisions at $\sqrt{s} = 200$ GeV for a fixed $dE_q/dx = 1$ GeV/fm.

1.) a γ-tag is just a tool to minimize the uncertainty in z
2.) measuring the non-identified charged hadron away-side spectrum is sufficient as long as the energy loss is universal

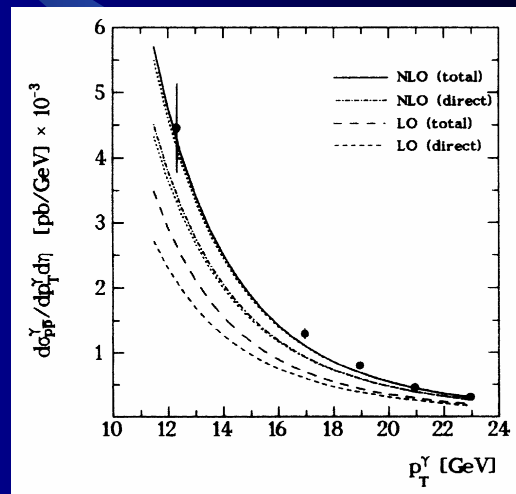
# Requirements for a complete γ-jet program

- Full coverage in tracking and pid and calorimetry
- Preferably γ-jets to determine jet energy unambiguously

Broadening in η and pT in pp (γ+jet) and AA




- Need hadronic calorimetry in order to apply isolation cuts for γ's




Glueck et al., PRL 73, 388

R2D rates per RHIC year:

40 GeV di-jets: 120k

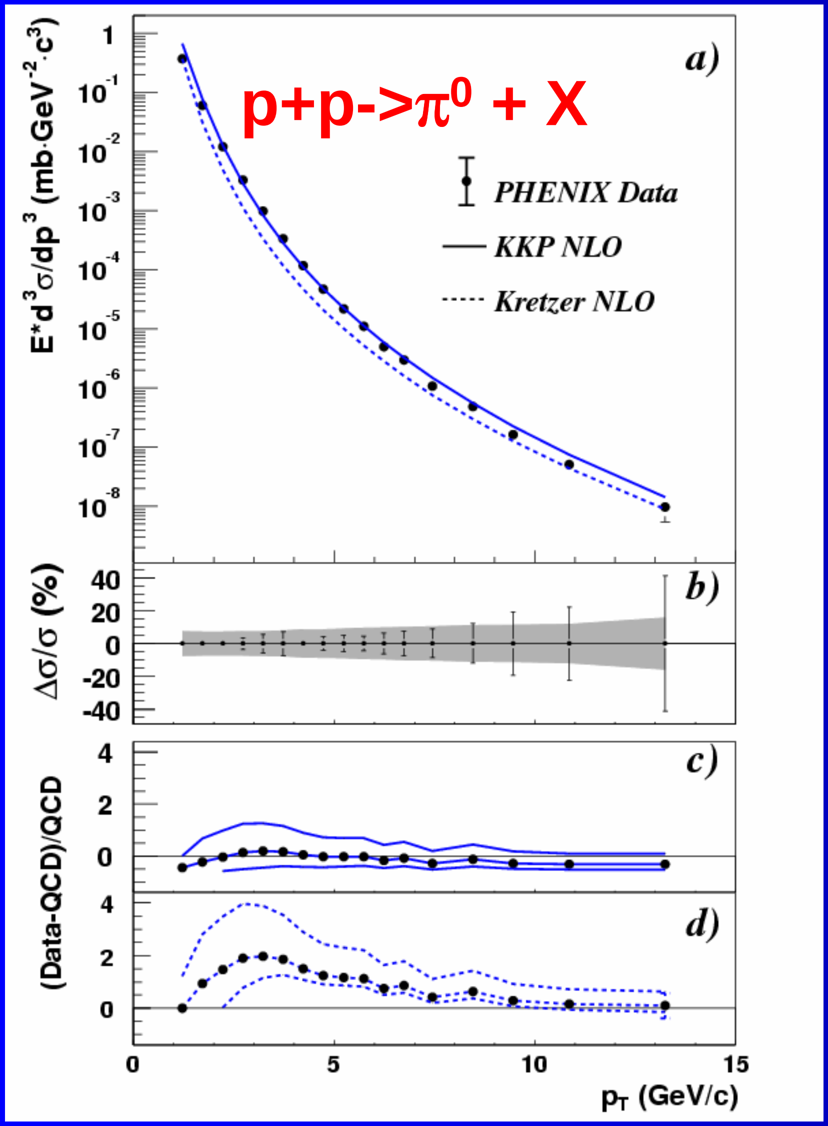
$N_{Ch}$ with pt>5 GeV/c in γ-jets with Eγ = 20 GeV : 19,000

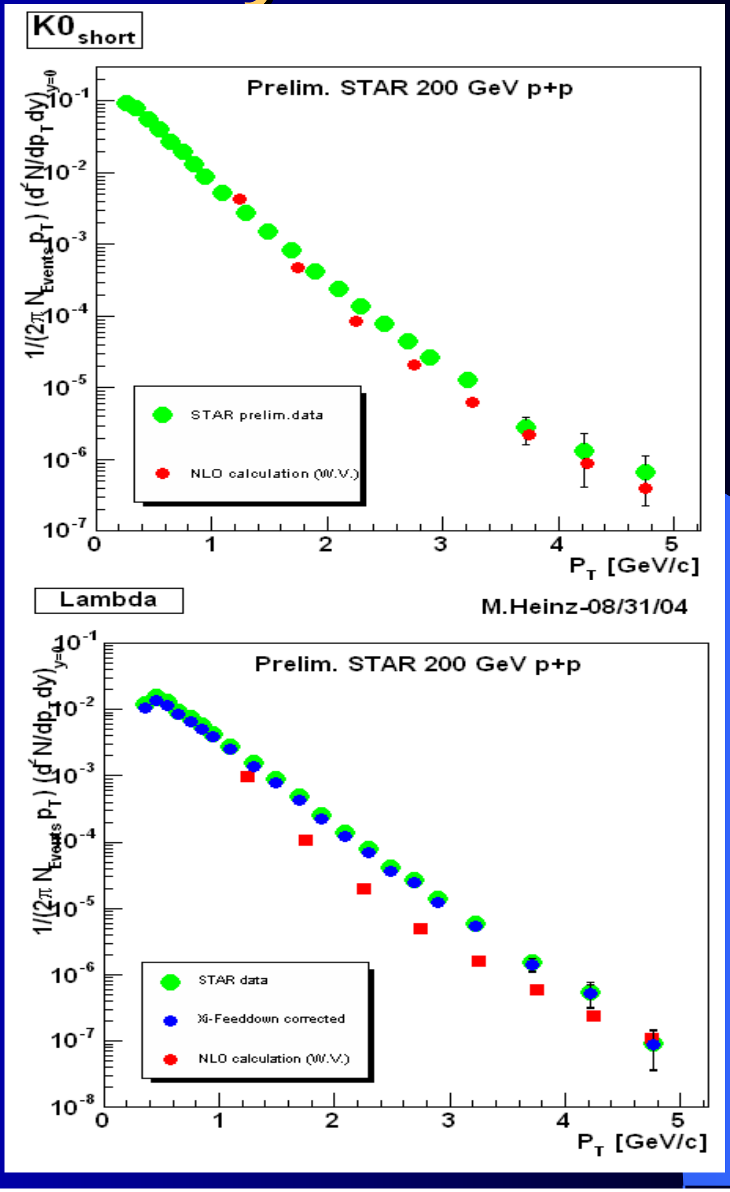
15 GeV: 200,000

10 GeV: 2,000,000

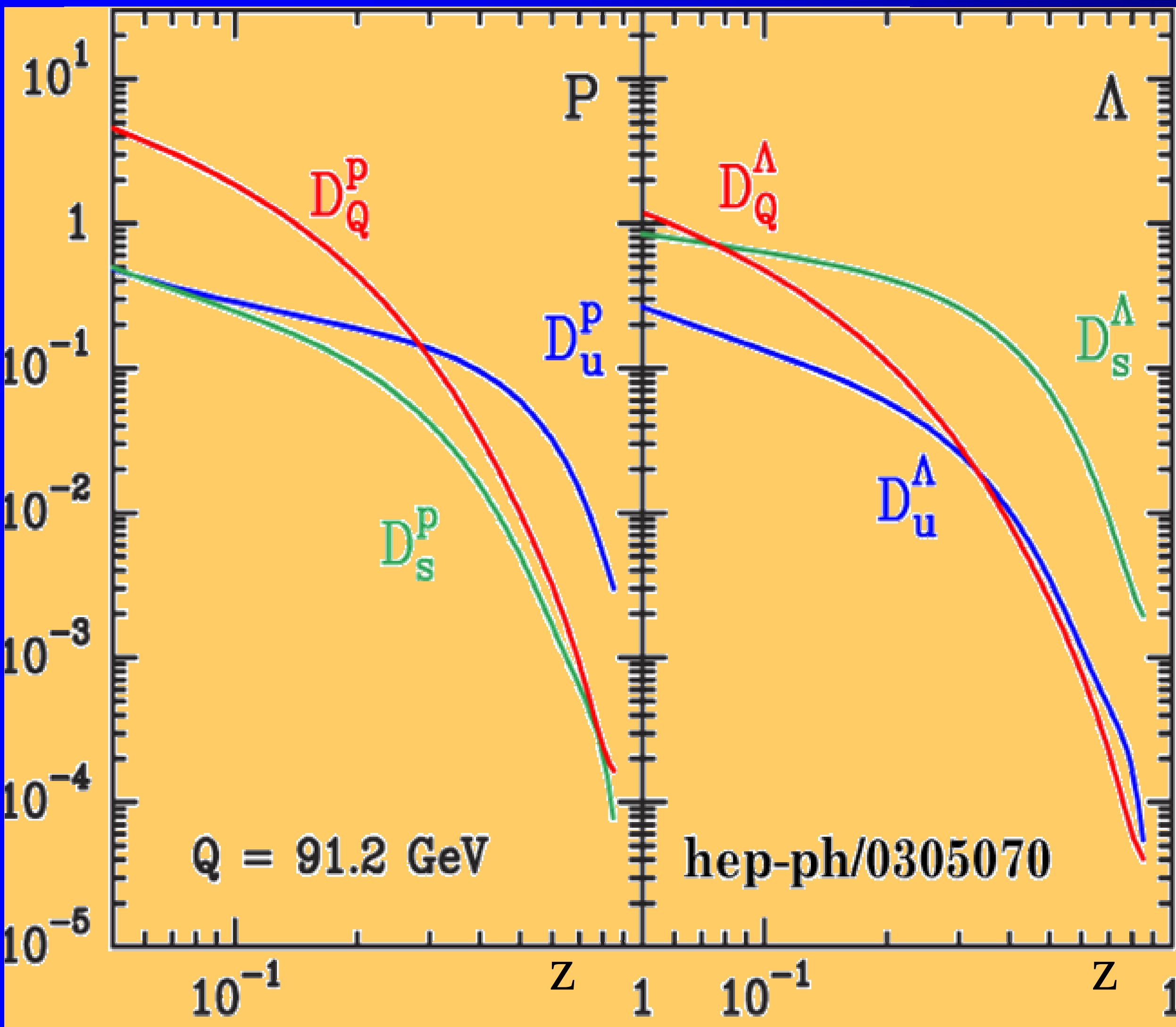
# High pt physics in pp collisions based on identified spectra

# pp at RHIC:
# NLO breaks down for heavy masses ?



# Octet baryon fragmentation
# Bourrely & Soffer (hep-ph/0305070)



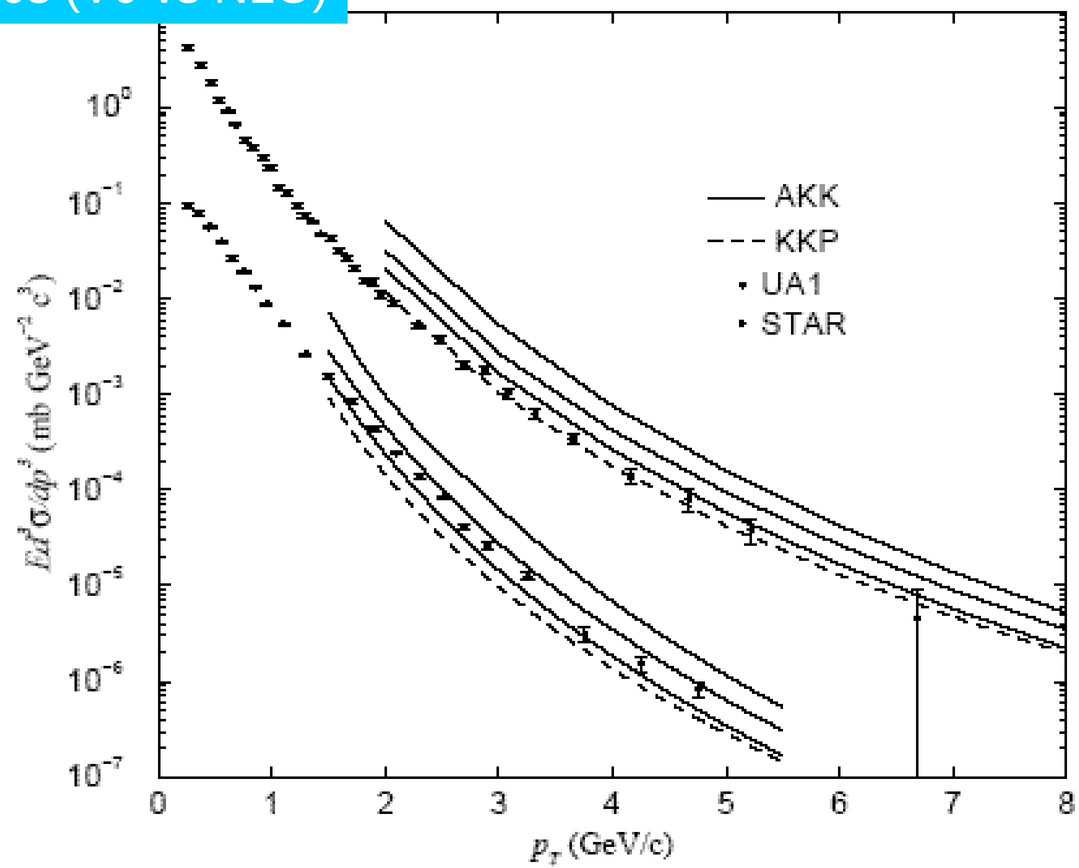

**Strong heavy quark contribution to parton fragmentation into octet baryons at low fractional momentum in pp !!**

**Quark separation in fragmentation models is important. FFs are not universal.**

**Depend on Q, $E_{inc}$, and flavor**

# New NLO calculation based on STAR data (AKK, hep-ph/0502188)

K0s (V0 vs NLO)




apparent $E_{inc}$ dependence of separated quark contributions.
As of now only tested on light mesons

# Correlations in pp: Study leading particle asymmetries

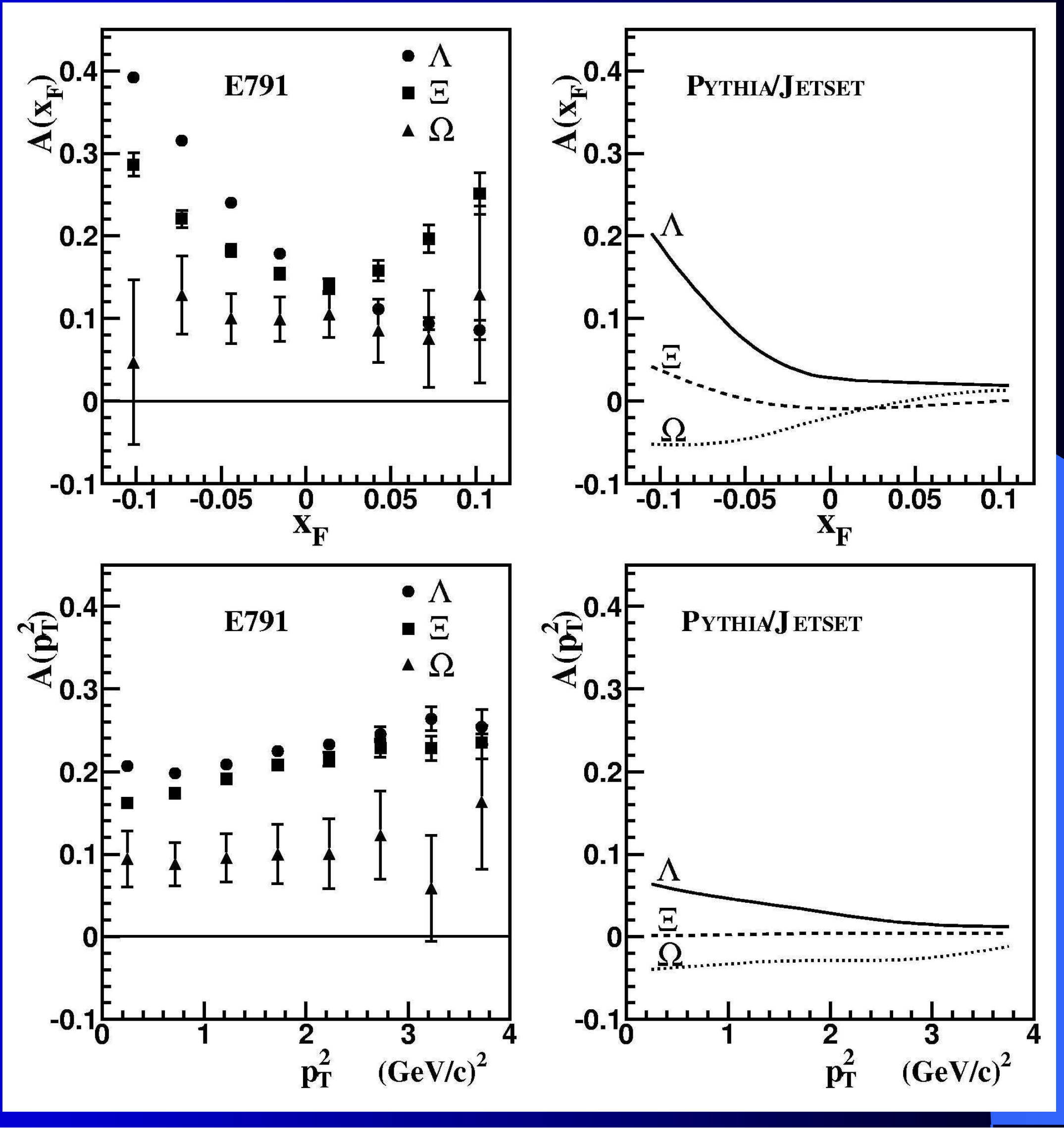
**Measured for charmed mesons and strange baryons (E791 – FERMILAB) (hep-ph/0009016)**

**Possible explanation through parton recombination (hep-ph/0301253)**

**Measure enhancement in the production of particles that have one or more valence quarks in common with initial state hadron.**

**Measure associated kaon and hyperon production.**

**Measure particle to antiparticle leading particle behavior.**



# Correlations in pp: Study identified particle correlations

Detailed particle identified measurements in OPAL, ALEPH and DELPHI show:

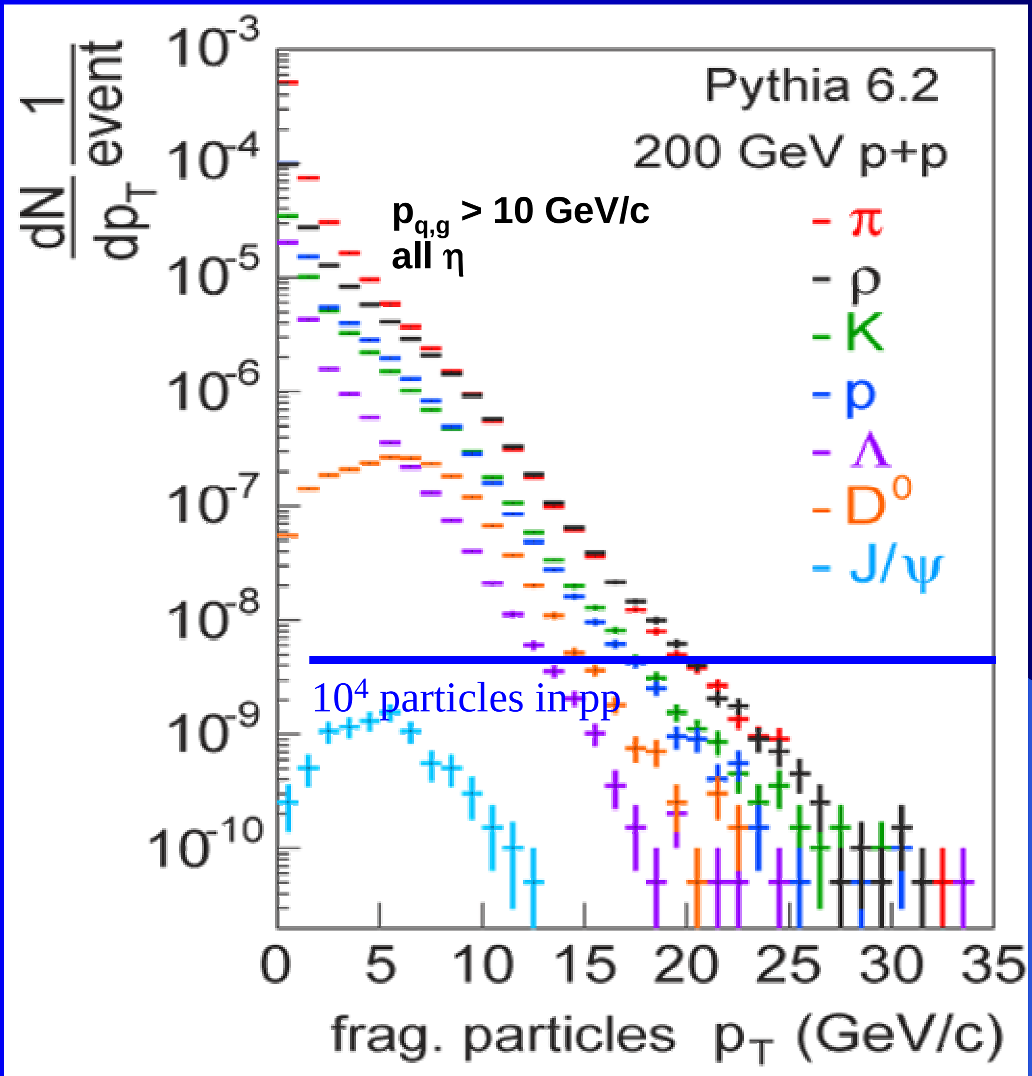
a.) cos(Θ) distribution between correlated pairs distinguishes between isotropic cluster (HERWIG) and non-isotropic string decay (JETSET) for production mechanism. JETSET is clearly favored by the data.

b.) strong local correlation of di-Λ production based on Δy measurements

c.) correlated Λ-AntiΛ pairs are produced predominantly within the same jet, i.e. short range compensation of quantum numbers.

Question: Are these features of jet correlations reproduceable in pp at RHIC and are they modified by the opaque medium in AA ?

# Are pp particle spectra at RHIC-II pt limited ?




Maybe

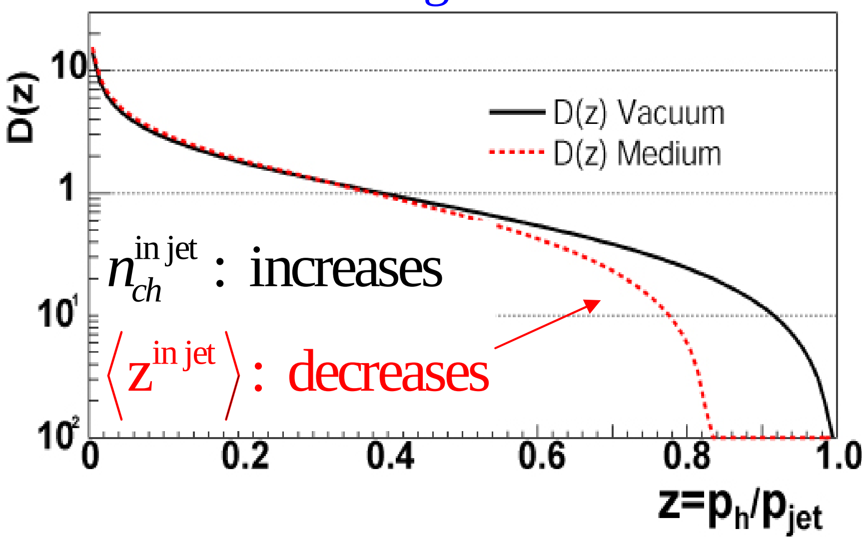
# High pt physics in AA collisions based on identified spectra

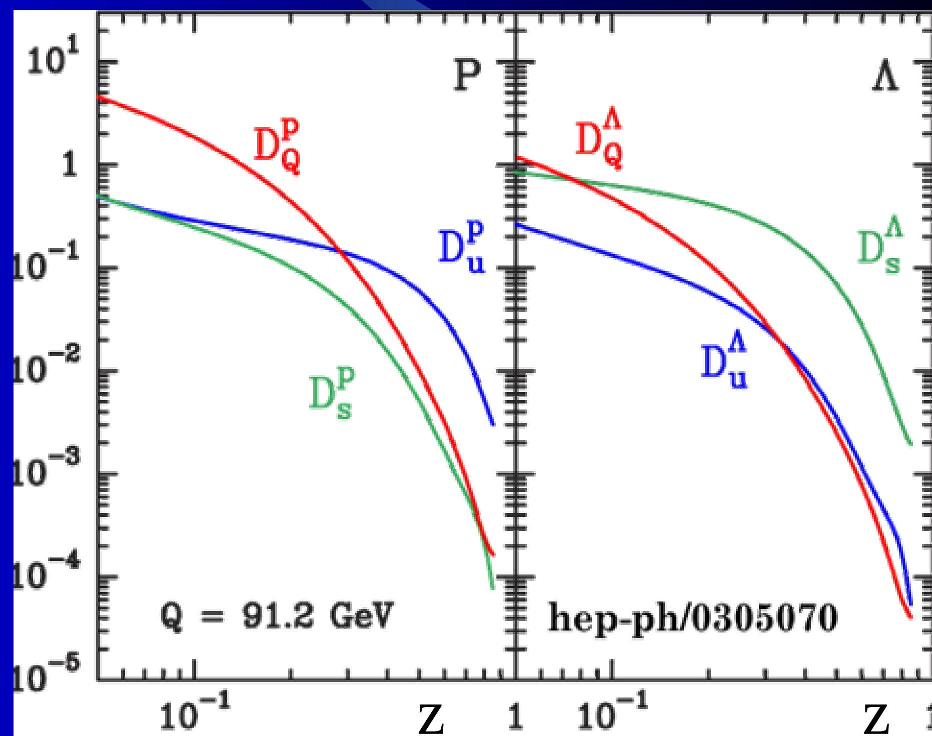
# Is the fragmentation function modification universal ?

Modification according to Gyulassy et al. (nucl-th/0302077)

Induced Gluon Radiation

- ~collinear gluons in cone
- "Softened" fragmentation



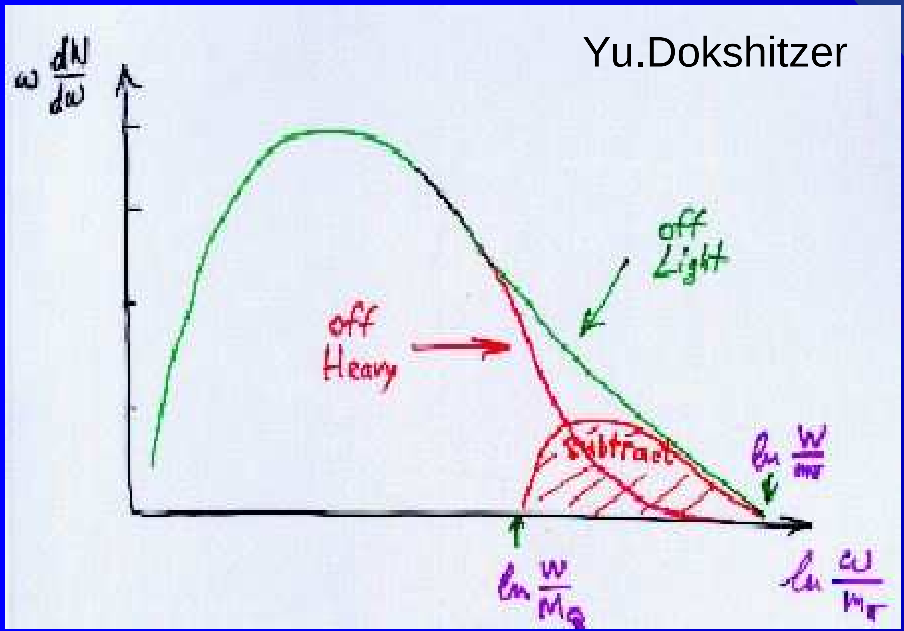




Quite generic (universal) but attributable to radiative rather than collisional energy loss

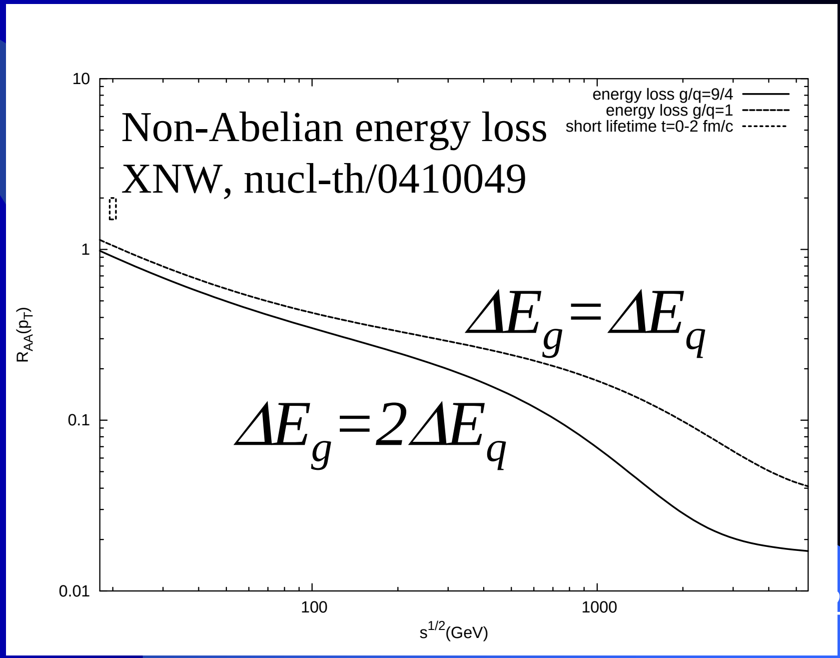
# Different partons lose different amounts of energy

**Examples:**

**1.) dead cone effect for heavy quarks: For heavy quarks in the vacuum and in the medium the radiation at small angles is suppressed (Dokshitzer & Kharzeev, PLB 519 (2001) 199)**




**2.) gluon vs. quark energy loss: Gluons should lose more energy and have higher particle multiplicities due to the color factor effect.**

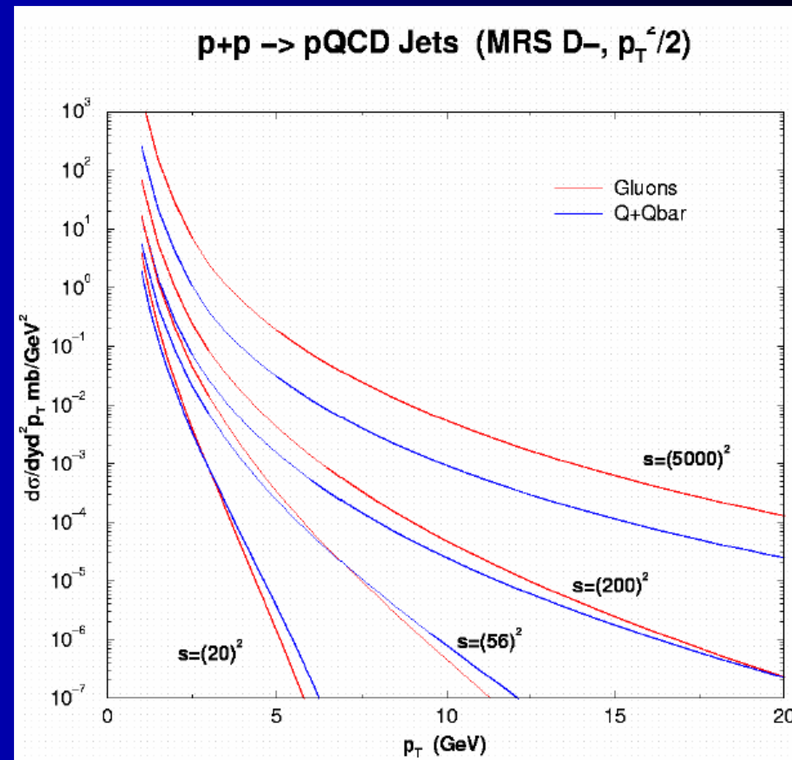


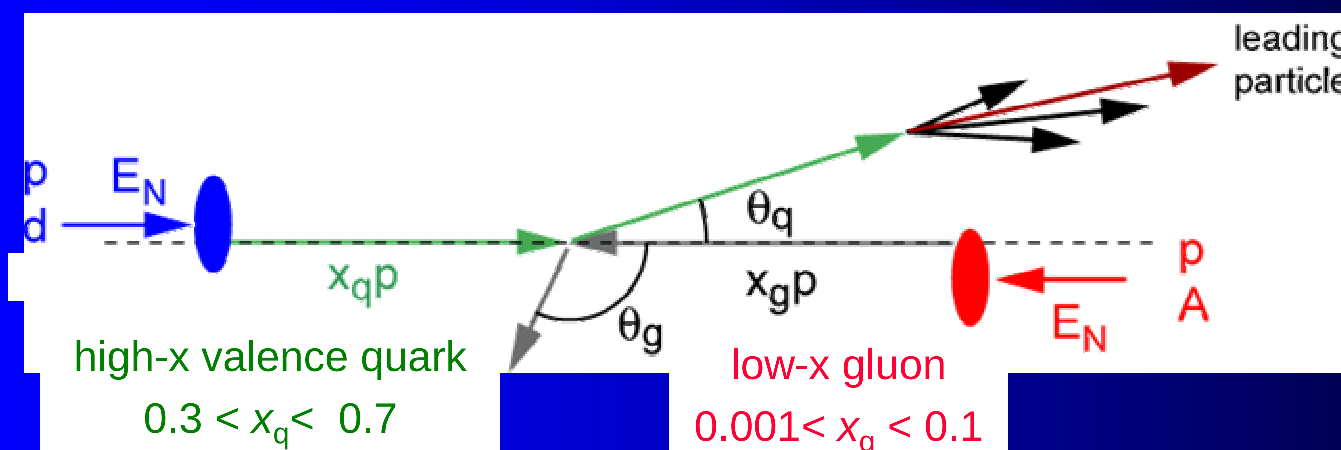
# Gluon jet selections at RHIC-II

1.) Large rapidity interval correlations
(Mueller-Navelet Jets)

2.) Three jet events (?)

3.) $P_T$-dependence of $\gamma$-jets (?)



# Measuring the universality fragmentation modification in the medium

1.) we need to understand fragmentation (hadronization) in pp collisions

2.) use the medium modified fragmentation functions in AA collisions

3.) Different flavor contributions to D(z) at different z lose different $\Delta z$ in the opaque medium.

**Measure fragmentation functions in pp & modifications in AA.**

**Study $z = p_{hadron}/p_{jet}$ and x dependence :**

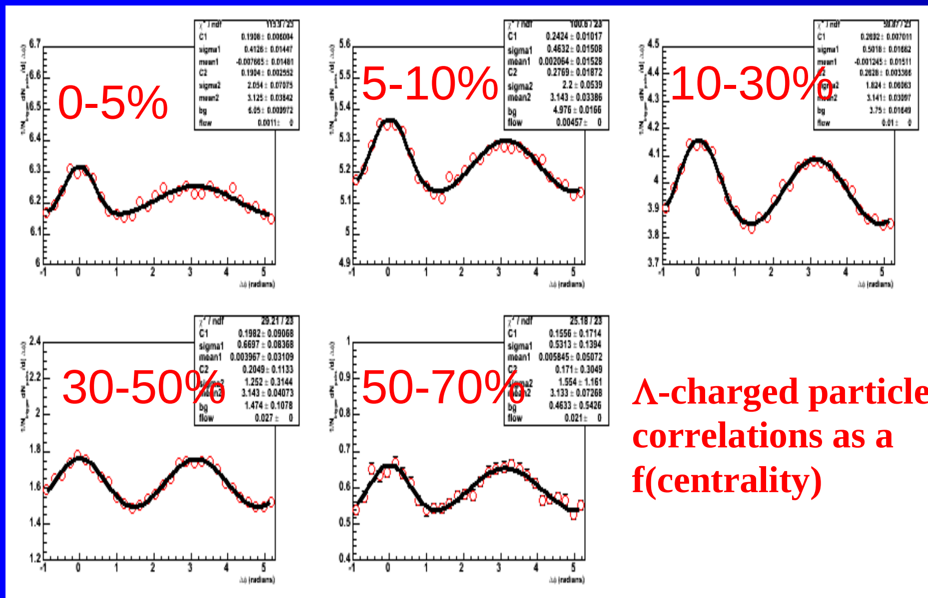
**$0.2 < z < 1 \rightarrow 7 < p < 30$ GeV/c**

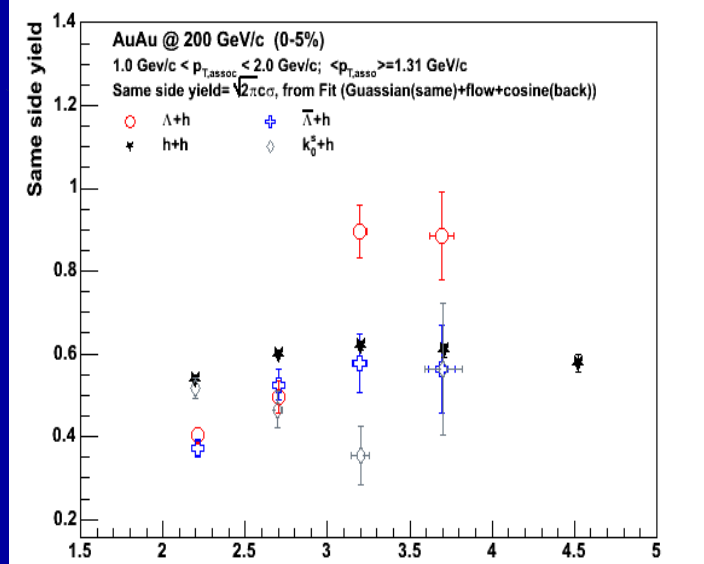
**$0.1 < x < 0.001 \rightarrow 0 < \eta < 3$**

**High $p_T$ identified particles**
**Intra- and inter-jet particle correlations**
**Large $\eta$ acceptance for $\gamma$-tagged jets**

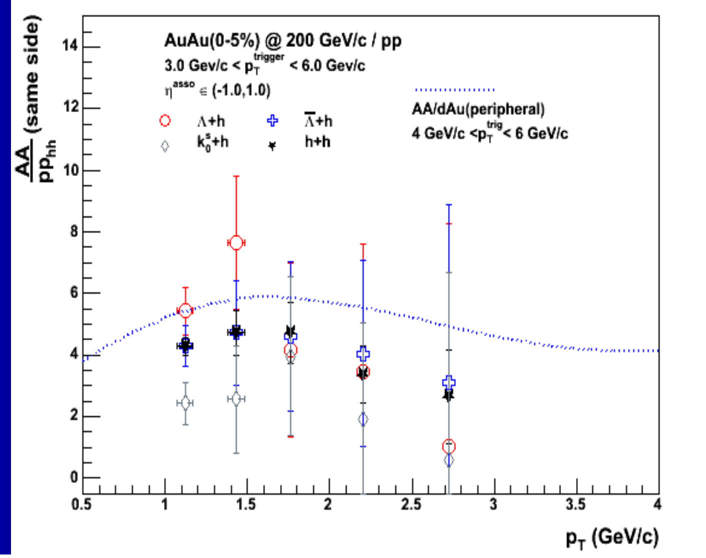
**Essential to understand hadronization**

# strange-charged hadron correlations in AA




STAR preliminary

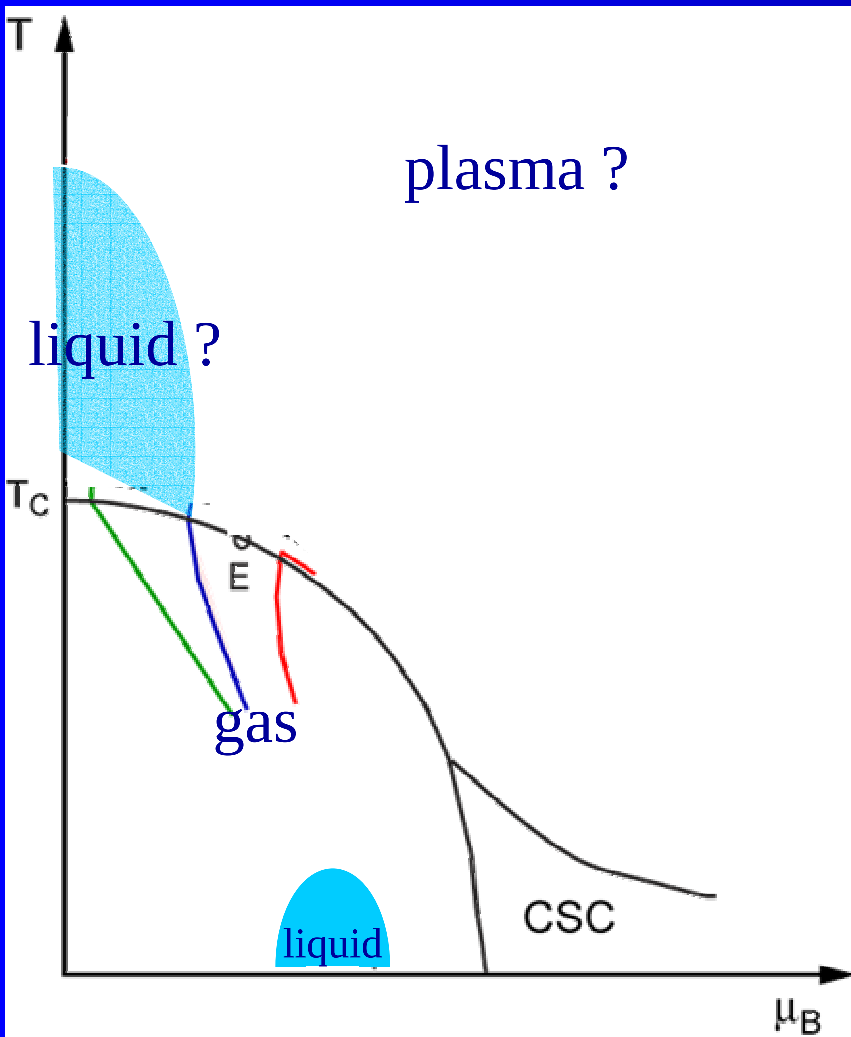



**No significant difference for different trigger particle species at intermediate trigger pt. Asymmetry might develop as a function of trigger pt (increased jettiness)**

**But we are statistics limited,**
**we need Λ–Λ, Λ-Anti-Λ, Λ-K to higher pt**
**Anticipated R2D rates:**
**50,000 ΛΛ pairs > 4 GeV/c , 5,000 pp pairs > 10 GeV/c**

STAR preliminary

# Exploring the phase above Tc

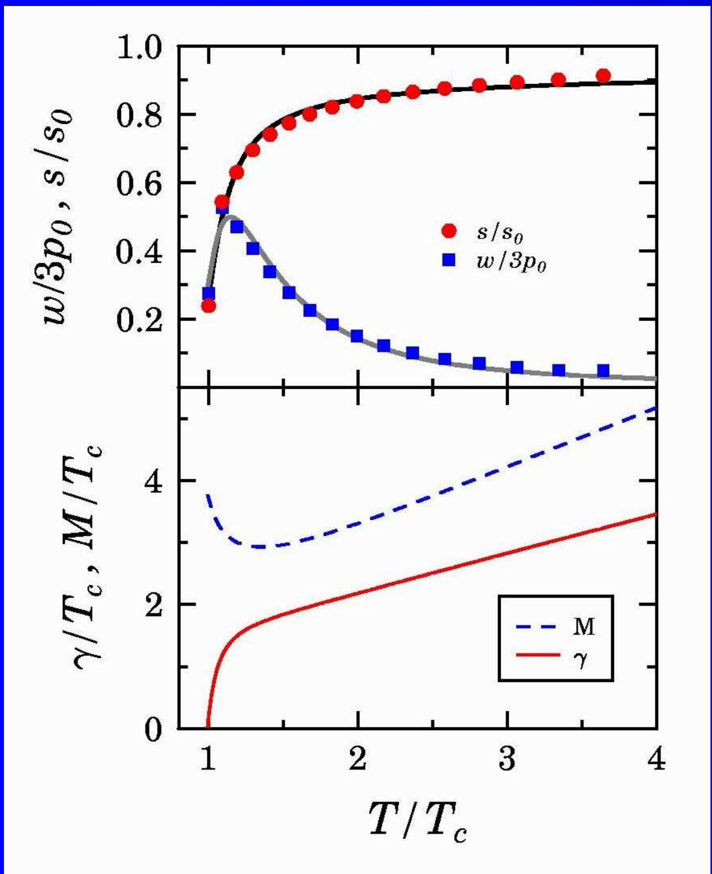



The unique method to generate asymptotic freedom experimentally, i.e. the interplay between compression, expansion, and temperature might lead to a strongly coupled state in a certain part of the phase diagram above the critical temperature.

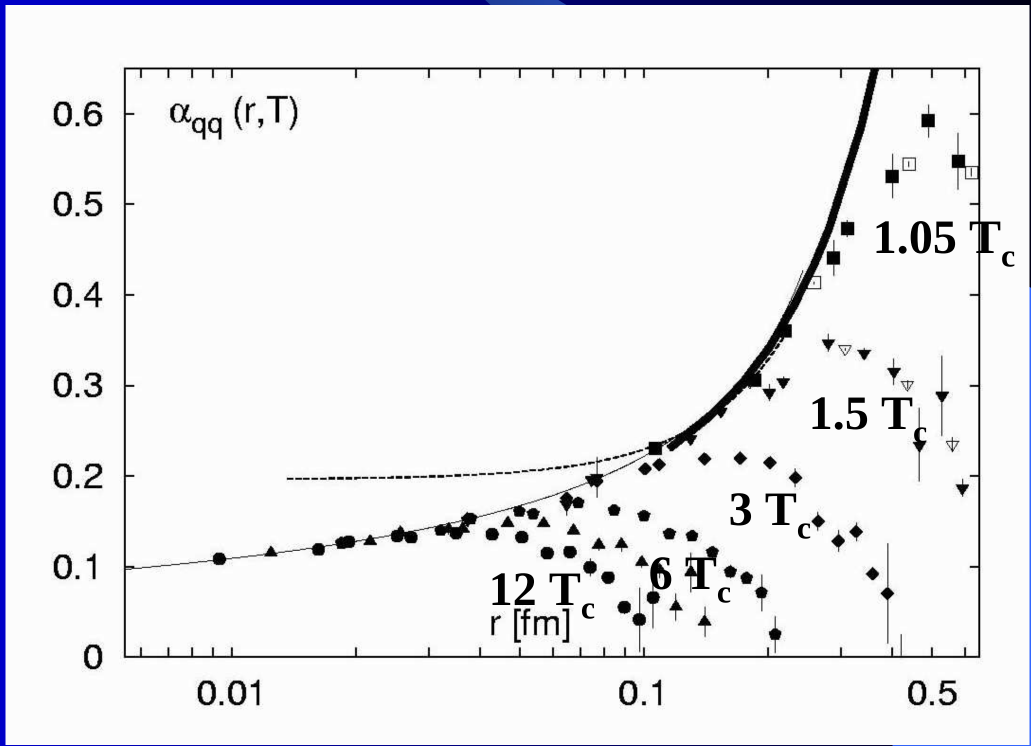
Is the coupling constant is running as a function of distance and temperature ?

# The temperature dependent running coupling constant $\alpha_s$

A.Peshier et al. (quasi-particles)
(hep-ph/0502138)



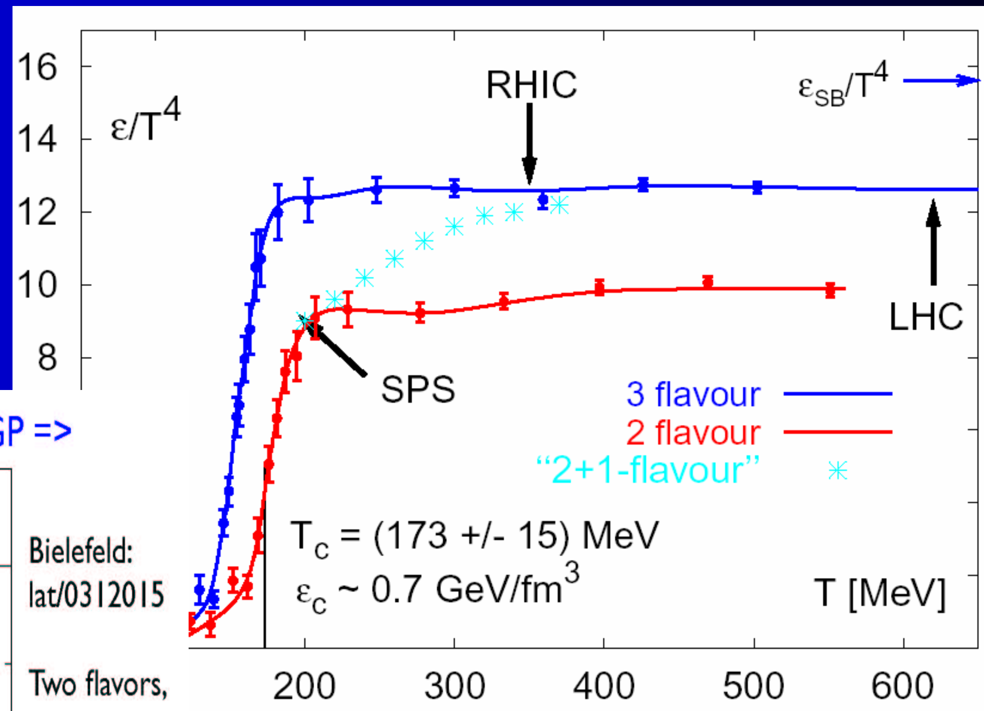

O.Kaczmarek et al. (thermal mass, LQCD)
(hep-lat/0406036)

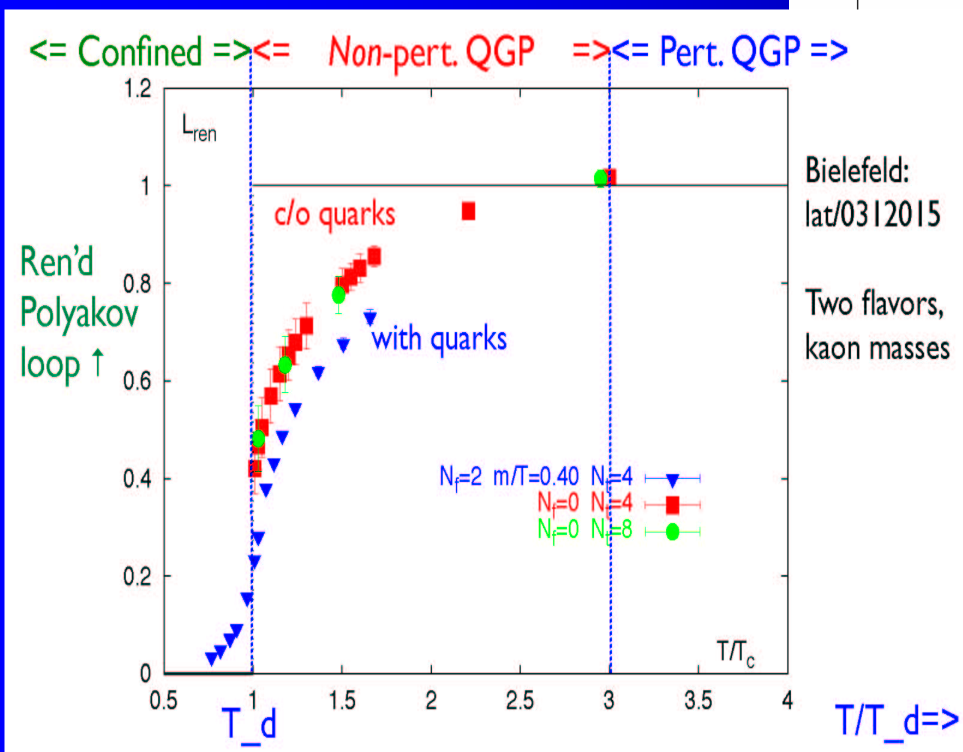



in an expanding system: interplay between distance and temperature

# How strong is the sQGP ?

Lattice QCD :
$\varepsilon/T^4$ never reaches the Boltzmann limit
No perturbative QGP
No wQGP




Polyakov Loop QCD :
Perturbative QGP (wQGP) is reached at $3T_c$
Different initial conditions at RHIC and LHC !

# The sQGP degrees of freedom

**Models with standard partonic degrees of freedom above $T_C$:**
Zhe Xu (hep-ph/0406278): multi-gluon interactions (e.g.strong 2 to 3)

**Models with massive colored degrees of freedom above $T_C$:**
Recombination models: constituent quark (dressed up valence quarks)

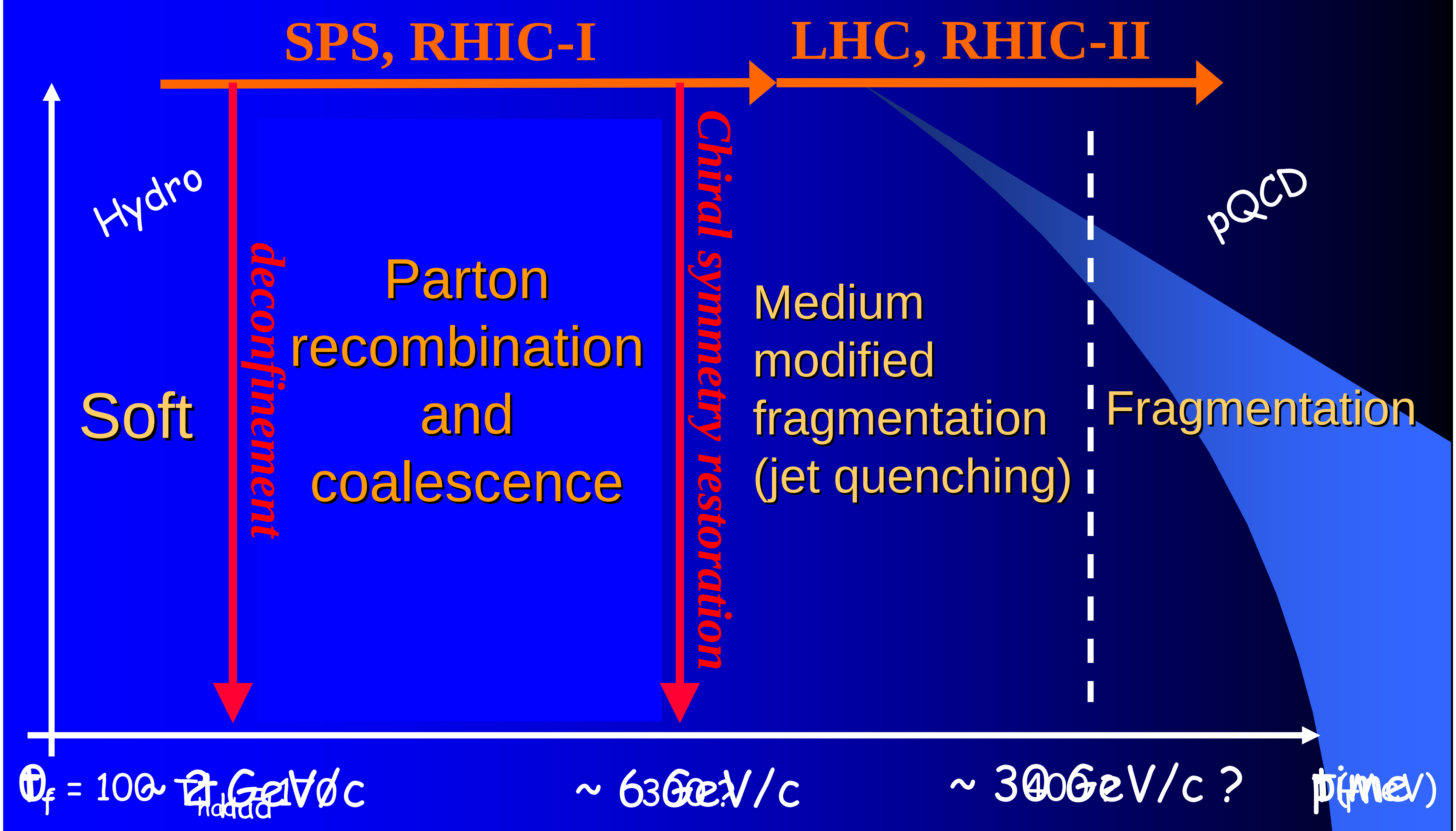
**Models with massless colored degrees of freedom above $T_C$:**
A. Peshier (Hirschegg 05): quasi particles above $T_c$
E.Shuryak (hep-p/0405066): colored and colorless bound states above $T_c$
R.Rapp (Hirschegg 05): quasi-resonant heavy states above $T_C$

**Let's learn from traditional plasma physics:**
M. Thoma (hep-ph/0409213): strongly coupled, non-relativistic plasmas

**Measurements :**

- **Elliptic flow $v_2$ - collectivitiy should reduce in a weakly interacting system**
- **jet quenching**
- **High mass resonance shifts due to partonic bound states (Shuryak)**

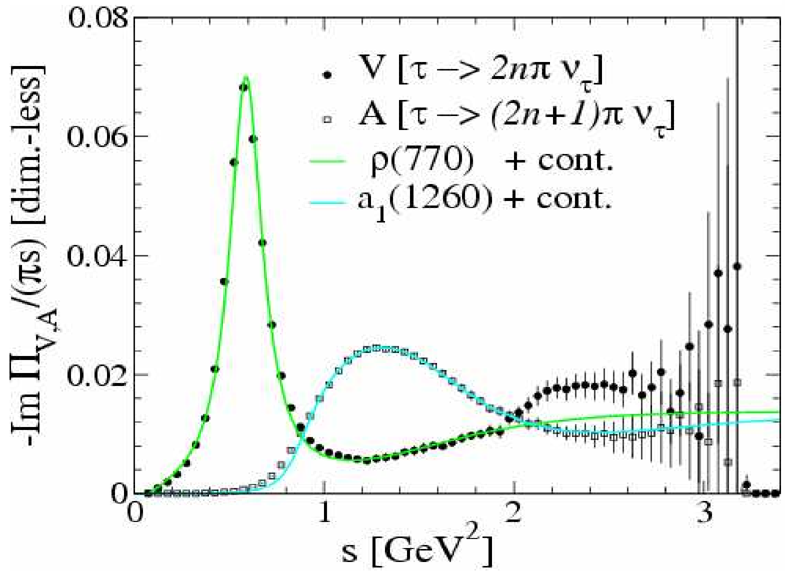
# What is the relevant scale for QCD ?



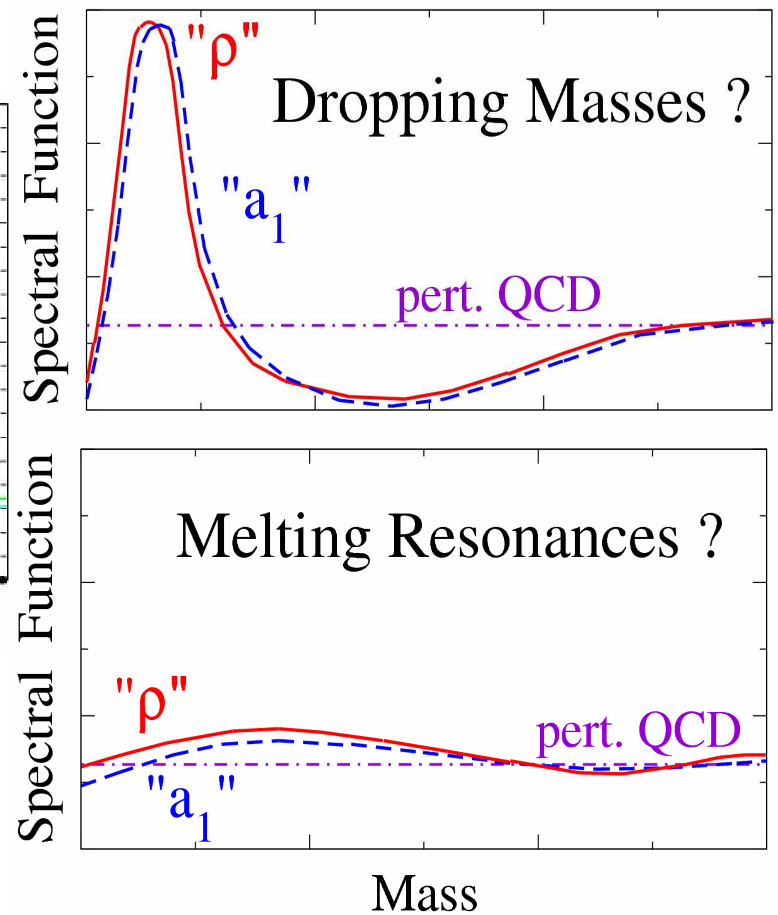
# Chiral symmetry restoration



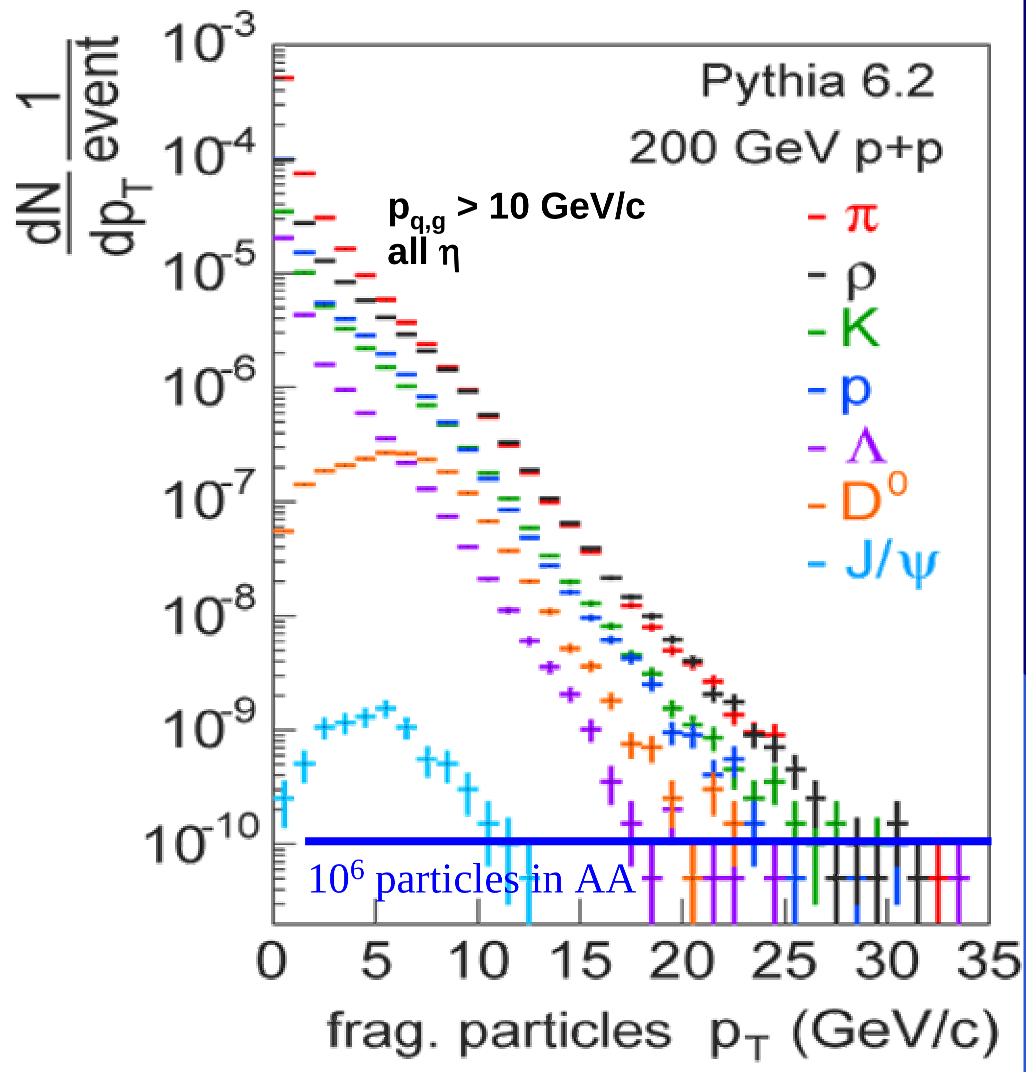
**Vacuum**




**At $T_c$: Chiral Restoration**

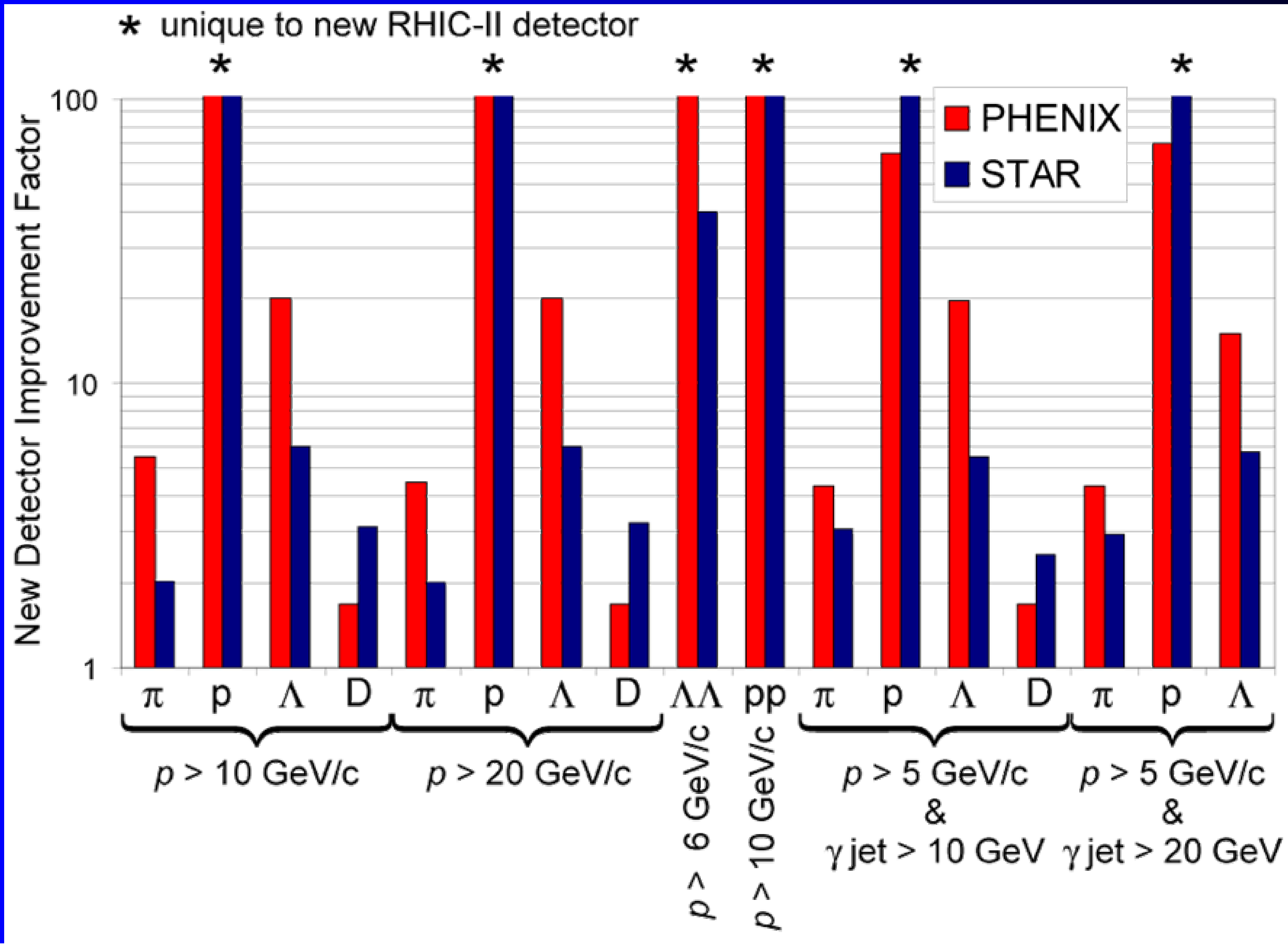


# Are AA particle spectra pt limited at RHIC-II ?




**NO !!**

# High $p_T$ Identified particles & jets in R2D



# Do we need RHIC-II in the LHC era ?

- Is the LHC viewing the sQGP through the distorted lens of the Color Glass Condensate ?

- Maybe the QGP degrees of freedom change from RHIC to LHC. Does the sQGP get weaker ? Are we in the sQGP sweet spot ?

- **The conditions will be different. This is a unique situation which allows us to study the QGP from two angles. RHIC-II offers longer running time, higher luminosity, more detailed detector capabilities. LHC offers higher energy and larger cross sections.**